Digital vs. Analog Equalization of Disc Record Playback

Traditionally, analog networks were used for frequency emphasis during recording of other than acoustic records. It followed that analog networks be used for frequency de-emphasis (equalization) during playback. The emphasis and de-emphasis networks complemented each other to produce an ideally flat frequency response. Most currently produced phonograph pre-amplifiers still use analog EQ. However, some individuals are saying that digital EQ is just as good – but is it? This study will hopefully help to answer this question.

I chose to do this comparison using the well-defined RIAA (Recording Industry Association of America)[1] de-emphasis equalization (EQ) response. In keeping with conventional usage, I'll refer to it as the RIAA playback response. But the comparison is also valid for *any* playback EQ that could be used for 78- or 45-rpm records. I will look at four cases:

1. Commercial 2/3-octave band and 1/3-octave band analog equalizers,
2. A commercial 1/3-octave band digital equalizer,
3. Several VST plug-ins running in a VST host (digital EQ),
4. The *DC8*[2] Virtual Phono Preamplifier and Parametric EQ (digital EQ).

Baseline

First, I need an analog baseline for the comparisons. The RIAA playback amplitude response is defined by several time-constants but these translate to amplitude-frequency pairs from 20 Hz to 21 kHz or higher. These values graph to a smooth curve as shown in Fig. 1. When an analog network is used, the phase response (Fig. 2a) as well as the time delay at each of the frequencies is also inherently defined. Fig. 2b (which intentionally has a linear frequency axis) shows the phase response is not linear[3] so we can rule out EQ's with a linear phase response. The RIAA time delay curve is not shown separately because it is included in each comparison graph. For this project I built a low-gain RIAA network: Fig. 3 shows the circuit diagram and its photo is in Photo 1. (This network matches the defined amplitude response within ±0.2 dB and has a correspondingly accurate phase and time delay responses.)

 © Association for Recorded Sound Collections 2012. All rights reserved. Printed in USA.

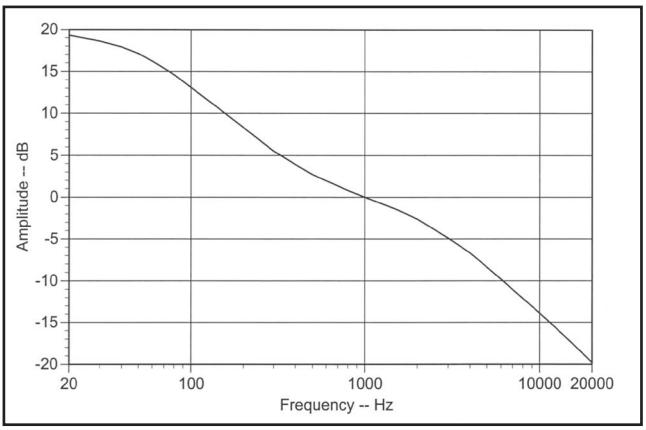

Figure 1: RIAA amplitude response measured on the baseline network. The measured values differ from the defined values by a maximum of ±0.2 dB.

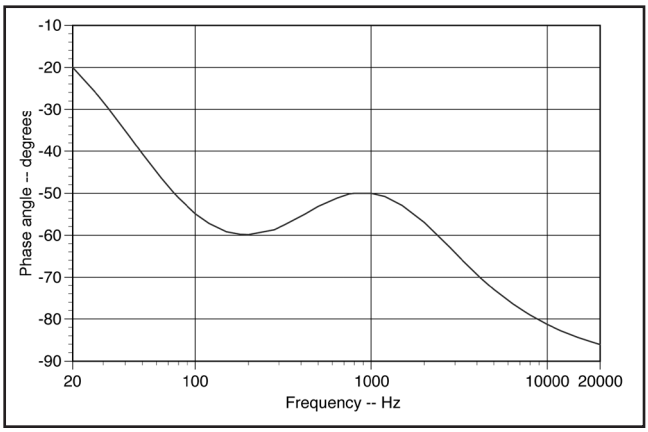

Figure 2A: Measured phase response of the baseline RIAA network, log frequency axis.

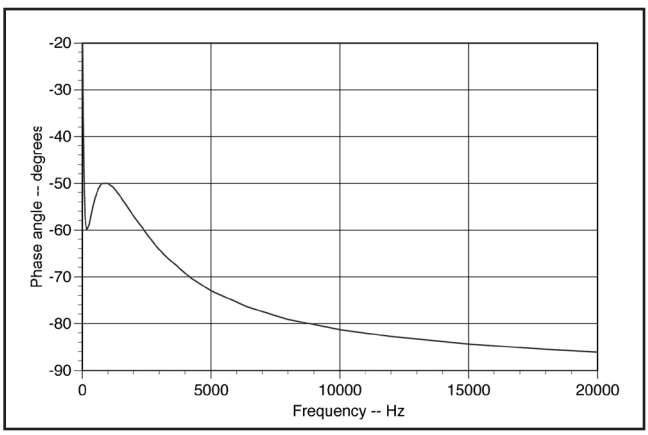

Figure 2B: Measured phase response of the baseline RIAA network with a linear frequency axis. The RIAA phase response is not linear. If it were, the phase response would be a straight line (see Reference 3).

2/3-Octave Band Analog EQ

For this comparison I used a *DOD* model *SR430Qx* EQ,[4] with the two mono channels in series to achieve the nearly 40 dB RIAA amplitude range. Using *TrueRTA's QuickSweep*[5] I first captured the amplitude response of my baseline network and saved it to the *TrueRTA* Workbench. Substituting the *DOD* EQ for the baseline network and using *QuickSweep* I adjusted the frequency band sliders to match the baseline curve. (This did take a while because I wanted a close match.) The result is shown in Fig. 4. The match is not too good at 20 kHz because a 2/3-octave band EQ has its highest frequency adjustment at a center frequency of 16 kHz. (I also did the match using pink noise but *QuickSweep* resulted in smoother curves.)

The next step was to measure the phase response of the *DOD* EQ. For this I used a *Dranetz* model 305 phase meter mainframe with a 305-PA-3007 plug-in[6] and a *Tenma* model 72-505 audio generator.[7] The *Tenma* generator has 36 frequency steps from 20 Hz to 20 kHz and this simplifies repeated measurements because it's much faster than using a continuously tuned generator and frequency counter. I recorded the phase readings with paper and pencil and then converted each value to time delay with a pocket calculator. The time delay is just the phase angle converted to time at each frequency.

$$T_d = \theta(1000) / 360\ f$$

Table 1: RIAA Baseline Circuit Parts List

Symbol	**Value**	**Description**	**Vendor**	Part No.
C1, C5	270nF 50V 5%	V-series polyester*	DigiKey	P4668
C2, C6	15nF 50V 5%	V-series polyester*	DigiKey	P4515
C3, C7	56nF 50V 5%	V-series polyester**	DigiKey	P4522
C4, C8	22nF 50V 5%	V-series polyester**	DigiKey	P4517
C9, C10, C11, C12	100nF 50V 5%	V-series polyester	DigiKey	P4525
C13, C14	470 uF 16V 20%	Radial electrolytic	Mouser	647-UVR1E471MPD
H1, H2, H3		3-pin header	Mouser	538-22-03-2031
P1, P2, P3		3-pin terminal housing	Mouser	538-22-01-2037
		Molex terminals	Mouser	538-08-50-0114
R1, R12	47K 1/4w 1%	Metal film	Mouser	271-47K-RC
R2, R3, R4, R5, R6, R8, R9, R11, R13, R14, R15, R16, R17, R19, R20, R22	10K 1/4w 1%	Metal film	Mouser	271-10K-RC
R7, R18	1100 1/4w 1%	Metal film	Mouser	271-1100-RC
R10, R21	1000 1/4w 1%	Metal film	Mouser	271-1000-RC
U1	TLC2274AIN	Op-amp	DigiKey	296-7123-5
U2	TLC2272IP	Op-amp	DigiKey	296-7117-5
		Circuit board	TDL	M4041C.PCB

* The C1 – C2 parallel capacitance selected to 285nF ±2%
* The C5 – C6 parallel capacitance selected to 285nF ±2%
** The C3 – C4 parallel capacitance selected to 78nF ±2%
** The C7 – C8 parallel capacitance selected to 78nF ±2%

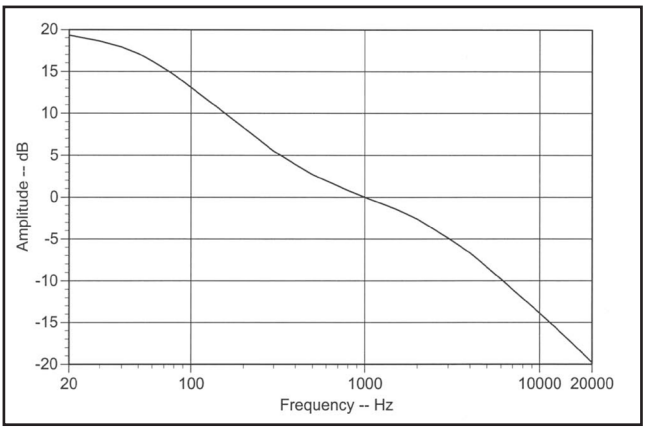

Figure 3: Low gain RIAA network for comparison baseline. Only one channel was used for this project. 1% resistors and matched capacitors produce a response that deviates no more than ±0.2 dB from the defined values.

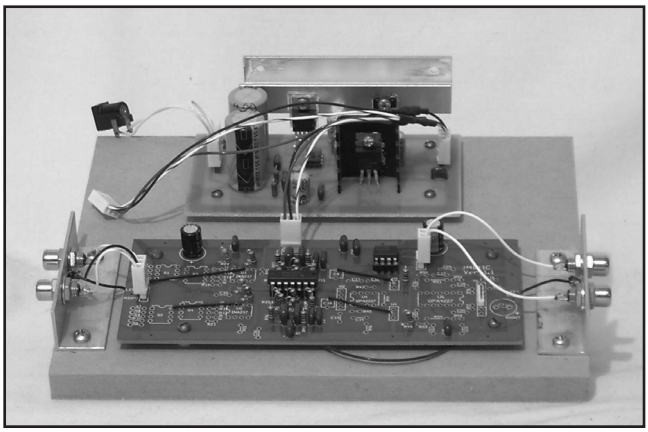

Photo 1: RIAA baseline circuit and power supply. (Any ±5 to ±8 VDC power supply can be used.) This low-gain circuit does not need shielding or low-noise opamps.

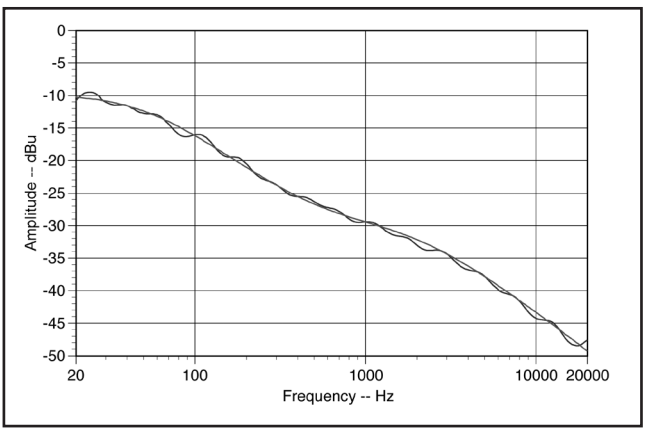

Figure 4: RIAA baseline and DOD EQ amplitude comparison. The slightly wavy line is the DOD EQ response.

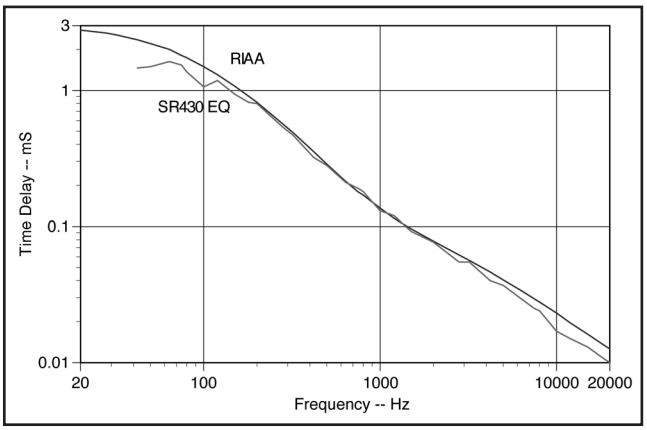

Figure 5: Time delay comparison of the baseline RIAA network with a DOD SR430Qx EQ adjusted to the RIAA amplitude response using QuickSweep in TrueRTA.

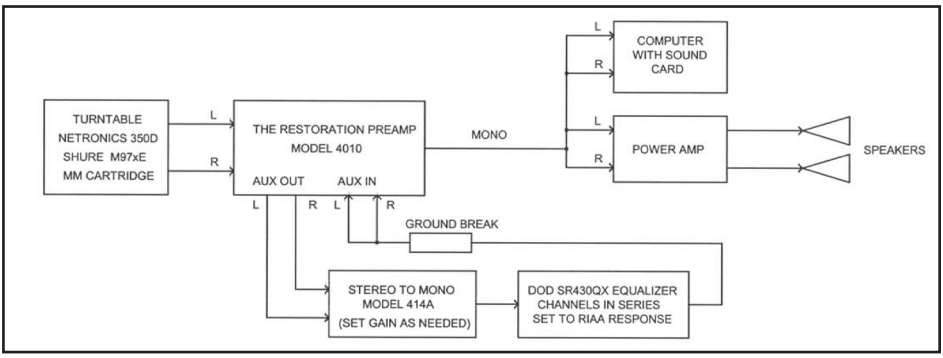

Figure 6: Equalizer test setup for listening and recording. The model 4010 is set to flat Turnover and flat Rolloff. Mode switch to L+R. Rumble filter to 20 Hz and HF Filter to 24 kHz.

Where T_d is time delay in milliseconds, θ is the phase angle in degrees and f is the frequency in Hz.

Please note that both axes (Fig. 5) are logarithmic – but so is the amplitude response in Fig. 4. Although the amplitude response is linear in dB, the Decibel is a logarithmic unit. I like the clarity of comparing time delays rather than phase but both are equally accurate.

The match in Fig. 5 is not too bad so I decided on a listening test. I played a selection of tracks from early LP records first with just a *TDL* model 4010 pre-amp[8] set to RIAA equalization and then with the 4010 set for flat equalization into the *DOD* EQ set to RIAA. This setup is shown in Fig. 6. (The *DOD* EQ needs the gain of a phono pre-amp to produce a useful output signal level.) The RIAA EQ network in the model 4010 is identical to the baseline network except the baseline network has much lower gain. In addition to listening, I recorded both EQ versions on the computer hard-drive at 96 kHz sample rate and 24 bit depth so I could send a comparison DVD to other listeners who may have a higher musical acuity than I do. Tracks 1 and 3 are from the *DOD* EQ and tracks 2 and 4 are from the model 4010 pre-amp.

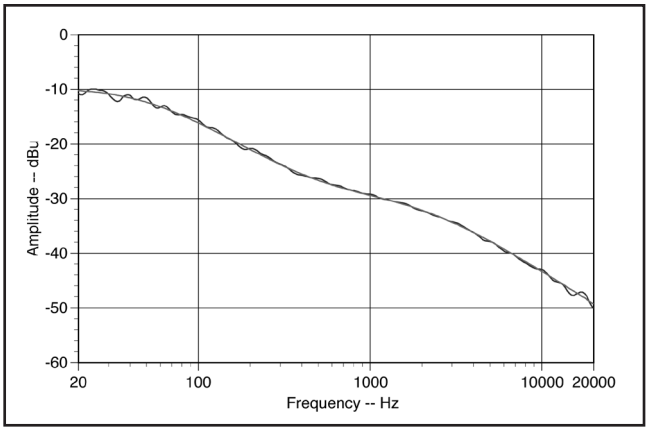

Figure 7: RIAA baseline and dbx231 EQ amplitude comparison. The wavy line has more "waves" from this 31-band EQ than from the 15-band DOD EQ.

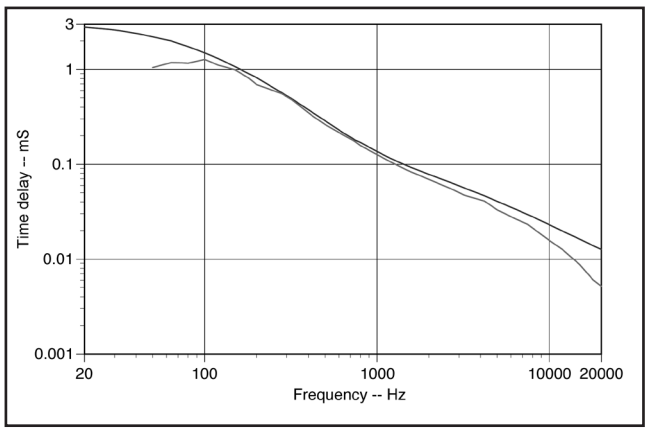

Figure 8: Time delay comparison: RIAA network to dbx231 EQ. The dbx EQ does not have as good a fit to the RIAA curve as does the DOD equalizer.

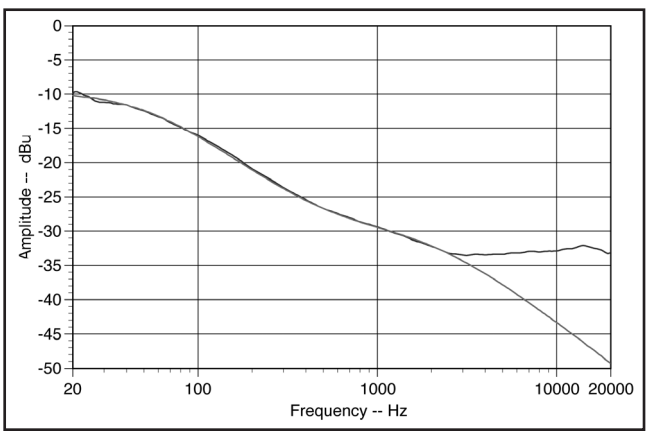

Figure 9: RIAA baseline and DEQ1024 EQ amplitude comparison. The match using this digital equalizer is very good in the 20 Hz to 2500 Hz range. Another DEQ1024 would be needed in series for comparison up to 20 kHz.

One listener commented as follows: "I first listened using my office computer's onboard Realtek sound chip and the tiny speakers in my monitor. I figured if I could hear a difference with a lo-fi rig it would be pretty telling. The difference was pretty clear to me. Tracks 1 and 3 sounded dull and lifeless, tracks 2 and 4 sounded like real instruments. The differences were even more telling when I listened in my music room; most notably in the area of bass definition. All-in-all, I would describe the sound of tracks 2 and 4 as more coherent. This is apparent as a more natural sound for each instrument, ease of distinguishing between instruments, and a greater sense of ambiance."

Other listener comments followed suit: the *DOD* EQ does not make the grade as a useful RIAA playback equalizer.

1/3-Octave Band Analog EQ

I used a *dbx* model 231S.[9] The ±12 dB range of each slider does not cover the RIAA amplitude range so I used the two mono channels in series. I imported the RIAA amplitude curve onto the *TrueRTA* Workbench and then, using *QuickSweep*, began adjusting the sliders to match the RIAA curve. With 62 frequency sliders this took an hour or more. Fig. 7 shows the results; the ripples in the *dbx* response pretty well correspond to the filter center frequencies. The time delay comparison in Fig. 8 shows a poorer match than the *DOD* EQ even though the frequency response match was as good if not better. This supports the "rule of thumb" that the least amount of EQ to do the job is best.

1/3-Octave Band Digital EQ

A *Behringer* model DEQ1024[9] was pressed into service for this comparison. I think the procedure has been sufficiently well described so I will just present the results. The amplitude match (Fig. 9) is quite good in the 20 Hz to about 2500 Hz range. With just one DEQ1024 I didn't have enough amplitude adjustment range to go to higher frequencies. The time delay comparison (Fig. 10) shows no match at all. This digital EQ is not at all suitable for trying to match the RIAA phase response. Those who recommend using a phono pre-amp with a flat response and then correcting the file with a digital EQ would not get good sound with the DEQ1024.

VST EQ Plug-Ins

Virtual Studio Technology was developed by Steinberg GmbH[11] to add modular virtual instruments and effects (such as EQ) to their *Cubase* digital audio workstation (DAW) software. By using a real-time host, a VST plug-in (such as an EQ) becomes a virtual EQ with its inputs and outputs being the sound card inputs and outputs. Measurements can be made on the virtual EQ just as if it were a hardware EQ.

There are many real-time VST hosts available: some free, some rather pricey and some "in between." I have evaluated several with four useful products listed here:

1. *Minihost*[12] is donationware, it's small in size and very easy to use. Its disadvantage is not being able to load more than one VST plug-in at a time. That is, you can't load two instances of an EQ to achieve the 40 dB RIAA amplitude range.

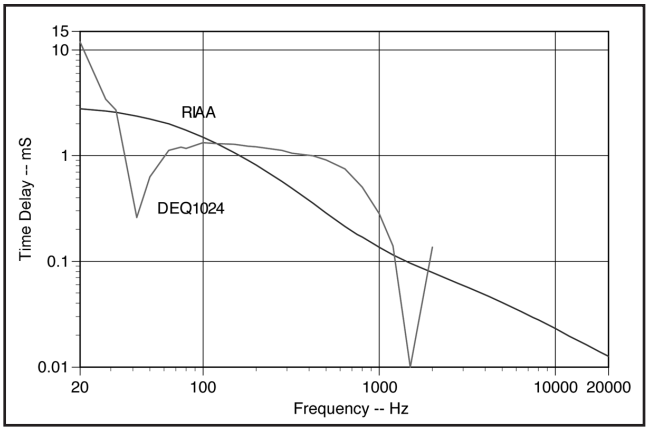

Figure 10: Comparison of the RIAA time delay to a Behringer DEQ1024 digital equalizer within the frequency band where there is a good match between the amplitude responses.

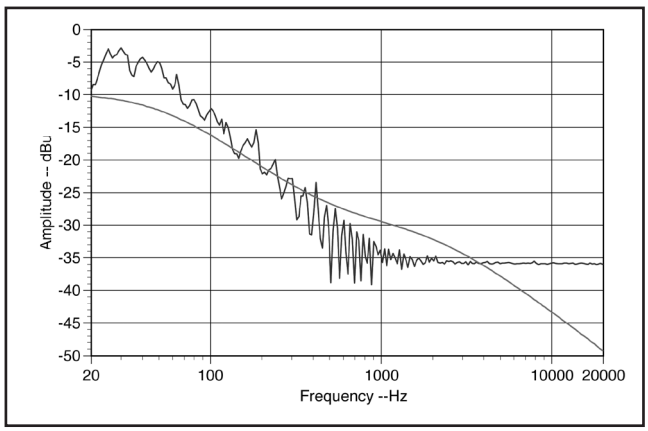

Figure 11: RIAA baseline and Anwidasoft GEQ31V 31-band VST EQ amplitude response comparison using TrueRTA QuickSweep. Two series instances of this EQ were setup in Cantabile to cover the 40 dB amplitude range. The GEQ31V has a digital readout to set the boost or cut for each frequency band.

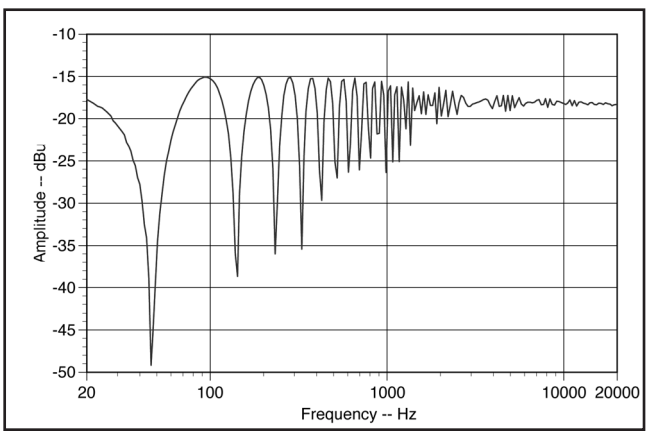

Figure 12: Amplitude response of the KarmaFX VST EQ using QuickSweep. All frequency band sliders were set to 0 dB (a flat line). This EQ has an amplitude range of ±12 dB.

2. *Cantabile Solo* 2.0[13] has a reasonable license fee and I think it's well worth it. It comes with a pdf format User Guide but using it is largely intuitive. Very powerful and will load several plug-ins at the same time.

3. *Cubase LE 4*[14] is a full-featured DAW and is "over kill" for this project. However, this older version is very reasonably priced and it can be activated online for free.

4. *REAPER* version 4[15] is also a full-featured DAW: it has a 398-page printed User Guide (for an additional charge) and a low license fee.

I used at least two host programs (mostly *Minihost* and *Cantabile*) for all plug-in measurements as a "sanity" check. It's important to be able to repeat results! After making measurements with several different plug-ins, it became apparent that the amplitude response could not be made to match the RIAA curve, Fig. 11. So I decided to try a "flat line" at 0dB to find out how much of a match is possible.

Fig. 12 shows the result of setting up this test on KarmaFX[16] running in *Cantabile*. A second computer is needed to supply a signal to the plug-in's input. In this case, I used *TrueRTA* to generate both *QuickSweep* and pink noise. The output is not a flat line and this shows why trying to match a smooth curve with *QuickSweep* or pink noise will not work. (A manual slow-sweep using a continuously tuneable audio generator and output voltmeter produced the same result.) I tried this on several of the other VST EQ plug-ins with much the same outcome.[17] In all the VST plug-in tests the input and output voltage levels were kept well below the clipping level of both the software and the sound card.

The procedure for running the above tests in *Cantabile* is as follows:

Use a second computer with its sound card output connected to the *Cantabile* sound card input, and launch *TrueRTA*,

Launch *Cantabile* and load an EQ plug-in,

Click the *Cantabile* Record drop-down menu to setup the recording choices,

Click the *Cantabile* Record button,

Click the *TrueRTA QuickSweep* button (or choose pink noise and click GO).

I did find one exception. The *Algorithmix*[18] LinearPhase PEQ Red produced a nearly flat line with *QuickSweep*, Fig. 13, when all ten filters were set to 0dB. But this is a linear phase EQ so its phase response would be incorrect even with a perfect amplitude match. Also, its license fee of 999 Euros puts it out of my reach for experimentation.

Virtual Phono Preamplifier in DC8

This built-in *DC8*[2] feature is basically a "re-equalizer" because it will accept an RIAA or flat input and output an RIAA or one of several "older record" equalizations. I chose

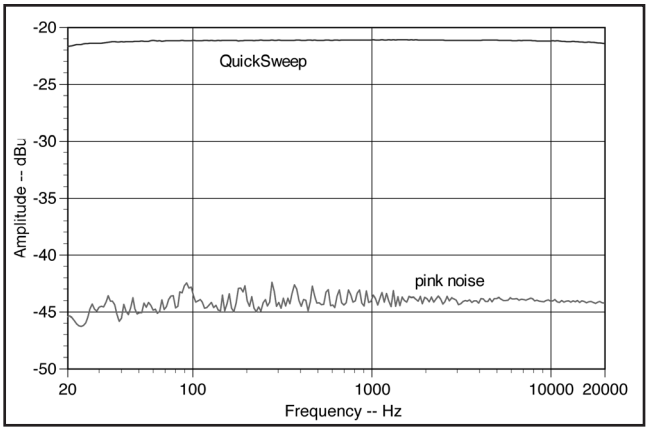

Figure 13: PEQ Red output with TrueRTA QuickSweep and pink noise inputs. All ten EQ filters were set to 0 dB gain and to the same Q (bandwidth) value.

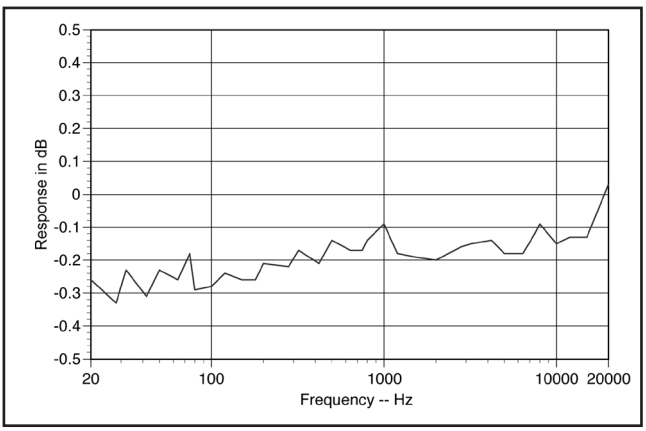

Figure 14: Amplitude response difference between the DC8 Virtual Phono Preamplifier and the calculated RIAA response. The DC8 VPP was set to Flat input and RIAA output with the Tone Controls disabled.

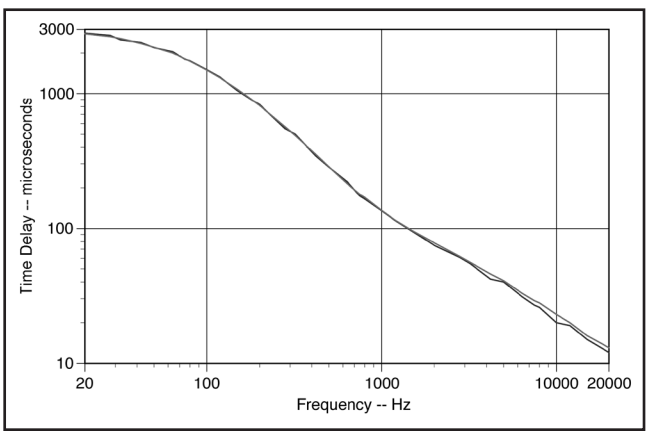

Figure 15: RIAA time delay (upper curve) compared to the DC8 VPP set to Flat input and RIAA output with the Tone Controls disabled.

to test the VPP with a flat input and an RIAA output. User setup is simple. In addition to radio-buttons for in and out selection it has check boxes for Tone Controls enabled or disabled and a 30 Hz Rumble Filter that can be turned on or off. And there are sliders for Left-Right Balance and Volume.

I recorded the same tracks used in the *DOD* EQ tests with the model 4010 pre-amp set to L+R, flat turnover and flat rolloff, 20 Hz Rumble Filter and HF Filter set to 24 kHz. I used the resulting files as the input to the VPP and recorded the output files which I sent to listeners for comments. While waiting for comments, I made amplitude and time delay measurements on the VPP.

I created an input file of 36 frequency bands from 20 Hz to 20 kHz (the same frequencies produced by the *Tenma* audio generator) for compatibility with previous measurements. Each band is 20 seconds in length and separated by 4 seconds of silence from the next band and all bands have the same amplitude so it's a "flat" recording. With the VPP set to RIAA output I recorded the equalized file. Playing the output file into an RMS voltmeter produced the values used in the Fig. 14 comparison graph. The maximum deviation is -0.33 dB at 28 Hz. The negative sign indicates the measured VPP values were lower than the calculated RIAA values.

The procedure for running this test is as follows:

Launch VPP in *DC8* and setup the user parameters as mentioned above (Tone Controls disabled, Rumble Filter on, Left-Right Balance centered and Volume to maximum),

Open the source file, in this case *tones.wav*,

In *DC8* click Record and setup the sample rate and bit resolution,

In the VPP window click Run Filter,

When the filter has finished running, click Files in *DC8*, click Save Destination As and give the output file a name.

I then made a composite stereo file with the left track the 36 equal amplitude frequency bands and the right track the VPP output. Using this file as the reference and signal inputs to the phase meter I recorded and graphed Fig. 15 comparing the measured time delay to the RIAA delay.

Although not identical, the curves are very close. (Even with a 96 kHz sampling rate there are some issues in making accurate time delay measurements at the higher audio frequencies: only 4.8 samples per cycle at 20 kHz.)

My primary reviewer commented as follows on the VPP equalizations:

"I didn't have a clear preference with the Pachelbel but I did with the Atkins. To my ears the VPP version had better instrument definition with clearer sound at all frequencies. The guitar sounded more like a real guitar while the 4010 version sounded slightly

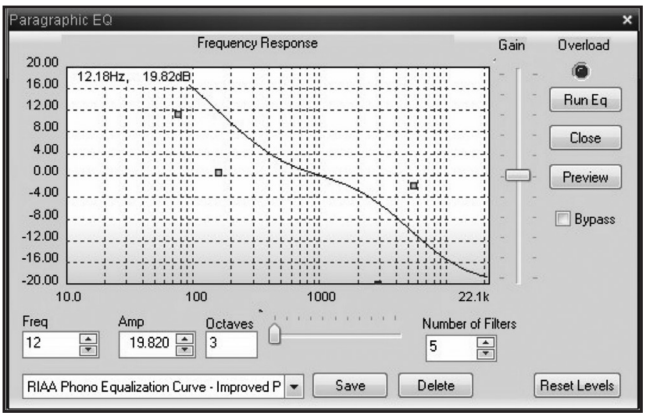

Figure 16: Screen shot of the DC8 Paragraphic EQ using the RIAA Phono Preamp - Improved preset.

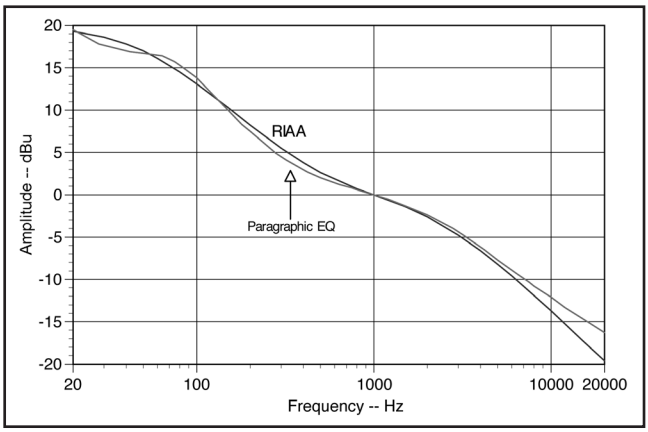

Figure 17: Comparison of the RIAA amplitude response to the DC8 Paragraphic EQ set to RIAA "Improved."

veiled. The VPP and 4010 versions are very close, and with different music choices I might slightly favor either one. At times, for example, I thought that the 4010 had a somewhat warmer sound on the Pachelbel."

Paragraphic EQ in DC8

The Paragraphic EQ is in the Filters pull-down menu. It has several presets and one of them is RIAA Phono Equalizer – Improved. When this is selected, we get the screen shown in Fig. 16. The amplitude measurement procedure was the same as for the *DC8* VPP with the RIAA comparison shown in Fig. 17. The match is not very good so I did not bother to make time delay measurements.

Sony Sound Forge[19] has a Paragraphic EQ but it has only four "peak" type filters each with a maximum bandwidth of 2.5 octaves so there is no way to match the RIAA curve.

Discussion

This has been an interesting and sometimes frustrating project with the following conclusions. General-purpose hardware analog EQ's are not useful for RIAA playback. And at this time, there seems to be only one digital RIAA EQ that's useful: the Virtual Phono Preamplifier (VPP) in *DC8*. My thanks to Don Walizer for being the "primary" music reviewer. He listened to quite a few different DVD versions of Side 1 of Chet Atkin's *Solo Flights* (RCA Victor LSP-3922) and Johann Pachelbel's *Canon in D Major* (Musical Heritage Society MHS-1060).

Others have recognized the importance of proper playback phase response when using digital EQ. For example, Gary Galo investigated this topic in a paper for the *ARSC Journal* [20]. He too found the VPP in DC versions 6 and 7 had the correct phase response (version 8 was not available at that time). He found that correct phase response could be achieved with IIR digital filters but not with FIR [21] filters which are still commonly used in digital EQ software, and apparently also in digital EQ hardware. Some manufacturers were unable to tell him which type of filter was in use in their products so this is another case of using an item that has been proven to function correctly, or else evaluating it yourself.

Ron Tipton *is president and principal designer at TDL Technology, Inc. (Las Cruces, NM), an electronics design and manufacturing company he started in 1957. He has degrees in electrical engineering from New Mexico State University and he is retired from a design engineering position at White Sands Missile Range. Ron has designed and built equipment for companies including Bose and Acoustic Research and worked as a consultant to GMS, Inc. (Prairie Grove, AR) designing guitar amplifiers and effects modules for Gretsch. He has authored contributions to a number of specialist publications, among them* audioXpress*,* Voice Coil*,* Multi Media Manufacturing*,* Poptronics*,* Nuts & Volts Magazine *and* Circuit Cellar.

Endnotes

1. The Recording Industry Association of America (RIAA) has defined a recording and playback standard for vinyl records produced since 1954. A table of frequency vs. gain (or attenuation) values can be found in many places. For example: http://www.bonavolta.ch/hobby/en/audio/riaa.html

2. *DC8* is the name of an audio editor and record restoration program from Diamond Cut Productions (version 8). It is available from http://www.diamondcut.com and from http://www.tracertek.com.

3. Linear phase is defined as: the property of a filter where the phase response is a linear function of frequency. That is, the phase response is a straight line when both phase and frequency are plotted on linear axes.

4. *DOD* is a manufacturer of hardware graphic equalizers and other audio processors. Product information is available from http://www.dod.com.

5. *TrueRTA* is a spectrum analysis program available from TrueAudio: http://www.trueaudio.com. All testing in this article using *TrueRTA* was done with the level 4 version. Demo versions and a free version (level 1) are available from their web site.

6. This phase meter features automatic frequency and input level ranging which greatly simplifies making measurements. This model is not in current production but pre-owned units may be found on ebay and from used electronic test instrument distributors.

7. The *Tenma* 72-505 Audio Generator is available from MCM Electronics: http://www.mcmelectronics.com.

8. The TDL model 4010 Phono pre-amplifier data and user guide (pdf format) can be found at http://www.tdl-tech.com/data4010.htm.

9. *dbx Professional Products* manufactures hardware graphic equalizers and other audio processing equipment. Product information at: http://www.dbxpro.com.

10. *Behringer* manufacturers a wide range of audio products including analog and digital graphic equalizers: http://www.behringer.com.

11. Steinberg GmbH manufacturers audio hardware and software: http://www.steinberg.com.

12. *Minihost* is a free VST plug-in host with full ASIO support. Although the download is free, a donation is appreciated if you use it regularly. Information and download from: http://www.tobybear.de/p_minihost.html

13. *Cantabile* is a VST plug-in host, professional and personal (Solo) versions, from TopTen Software. A free trial version is available and the Solo version registration fee is reasonable. http://www.cantabilesoftware.com.

14. *Cubase* is a product of Steinberg GmbH: see number 11 above.

15. *Reaper* is a full-featured Digital Audio Workstation (DAW). It performs as well or better than DAWs costing many times its registration fee: http://www.reaper.fm.

16. *KarmaFX* is a 31-band VST EQ. It's free but a donation is appreciated from frequent users. Unlike many free programs, it has a useful User's Manual. Pdf Manual and download from: http://www.karmafx.net.

17. Many VST EQs are available online. Some are free and some have a license fee (usually after a free trial period). Use your favorite search engine to look for VST EQ plug-ins.

18. *LinearPhase PEQ Red* is a VST EQ plug-in from Algorithmix GmbH. You can visit their web site for product information and to request a link to download a trial version and the Operator's Manual (a pdf file). http://www.algorithmix.com.

19. *Sony Sound Forge*, version 10 is an audio recording and editing program available from http://www.sonycreativesoftware.com and from many audio software distributors.

20. Galo, Gary A. "Phase Equalization and its Importance in the Reproduction of Disc Records" in *ARSC Journal*, 2010;41(1):83-96.

21. IIR (Infinite Impulse Response) and FIR (Finite Impulse Response) digital filter theory is beyond the scope of this paper but many texts are available. For example, see Williams, Arthur B. and Fred J. Taylor *Electronic Filter Design Handbook*, McGraw-Hill, Inc., Second Edition 1988.